Time spectroscopy for nuclear excitation experiments, with a Si avalanche-diode detector

S. Kishimoto
Photon Factory, High Energy Accelerator Research Organization

Outline

- Nuclear excitation experiments using SR X-rays
- An avalanche-diode detector
- Nuclear resonant scattering and inelastic scattering
- Nuclear excitation by electron transition (NEET)

Nuclear excitation experiments using synchrotron X-rays

Ex. Nuclear resonance of ^{57}Fe: 14.4keV, $T_{1/2}$=98ns, $\Gamma=4.7\times10^{-9}$eV

Beamline PF-AR NE3

At the several-bunch mode operation

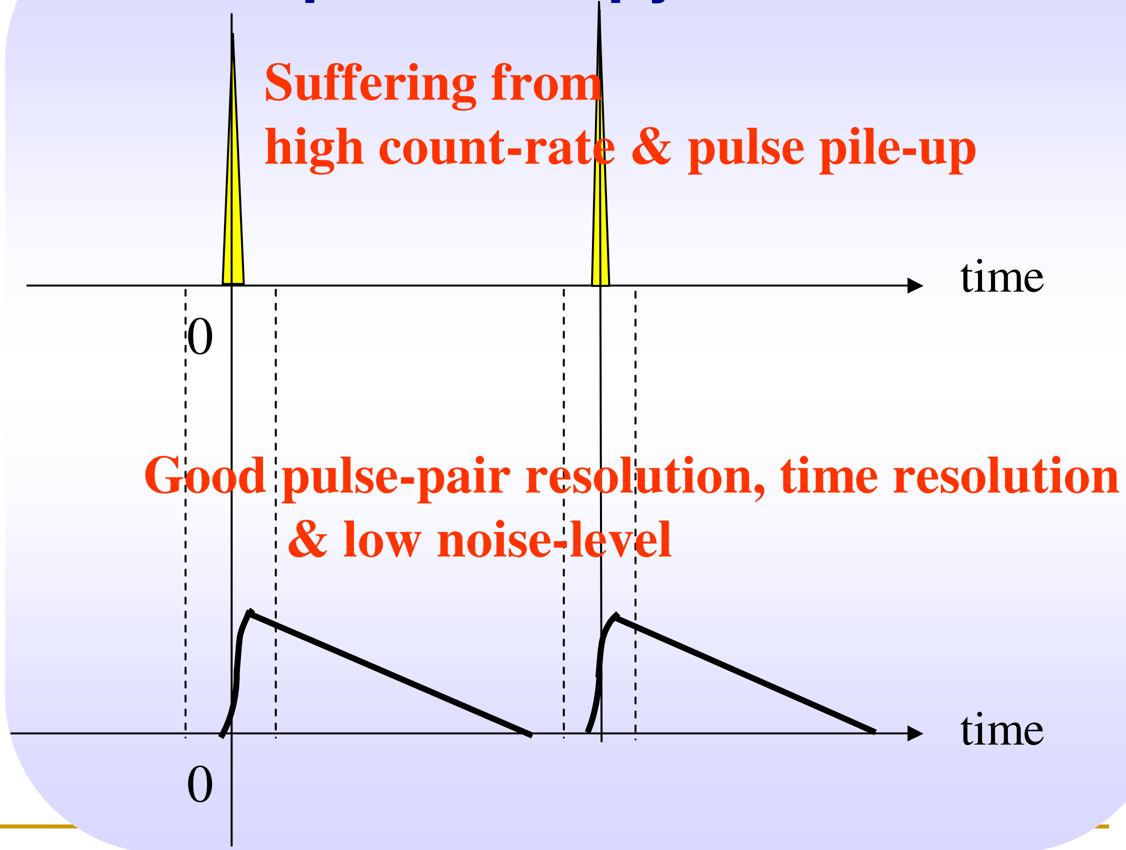
Prompt pulse by electron scattering ➡

Intense!

Radiation emitted from nuclei ➡

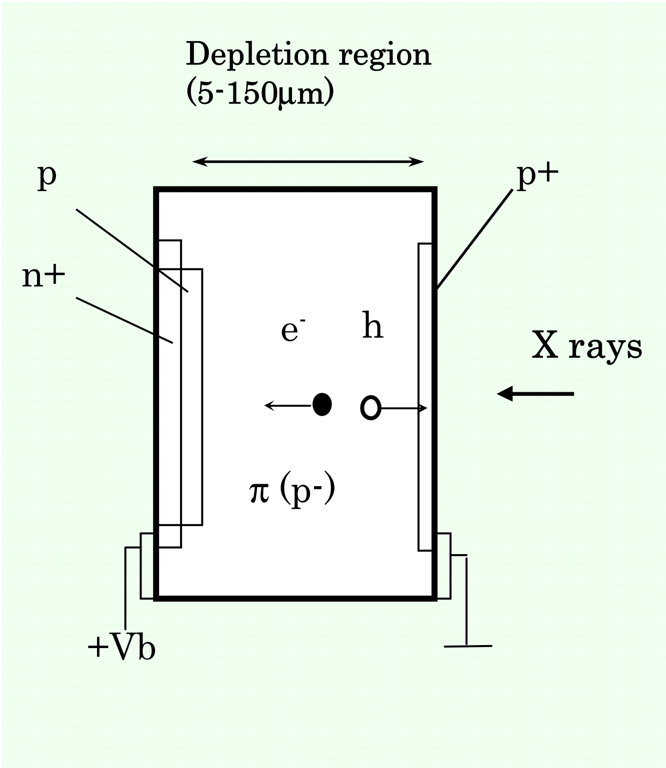
Weak !

Time spectroscopy



Avalanche diode detectors

A silicon avalanche photodiode (Si-APD) detector is a powerful tool for Synchrotron X-ray experiments.



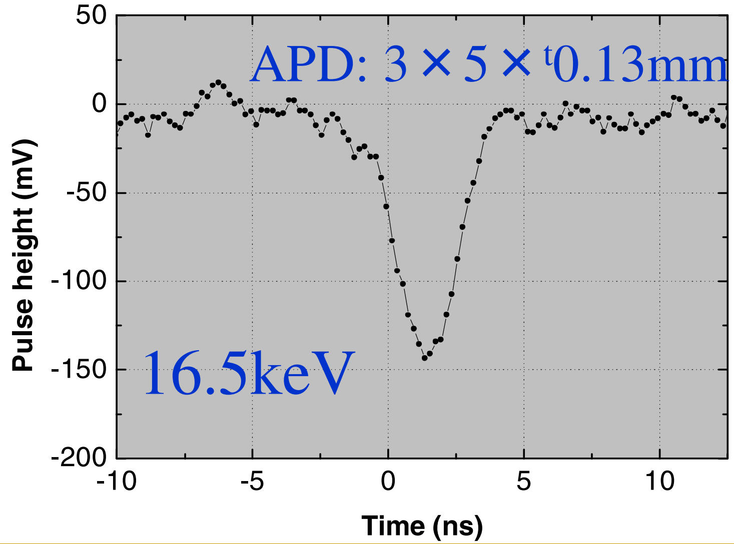
Detecting radiation Without a scintillator

Processing signals With a wide-band amplifier (gain>100)

➡ a nanosecond-width pulse for one X-ray photon

high-rate capacity : up to 10^8 s^{-1}

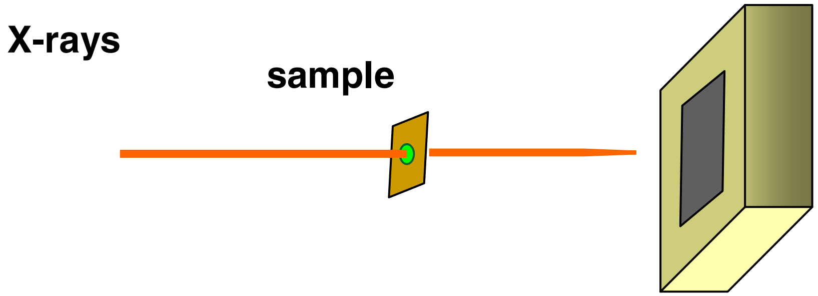
time resolution : < 50ps – 1.5ns



APD detectors for Nuclear Resonant Scattering

^{57}Fe: 14.4keV, $T_{1/2}$=98ns

Mössbauer time spectroscopy using time structure by the interference of hyperfine transitions

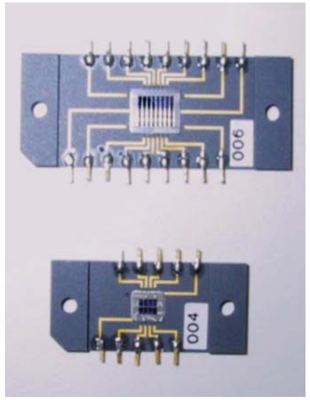


A stack of Si-APD plates

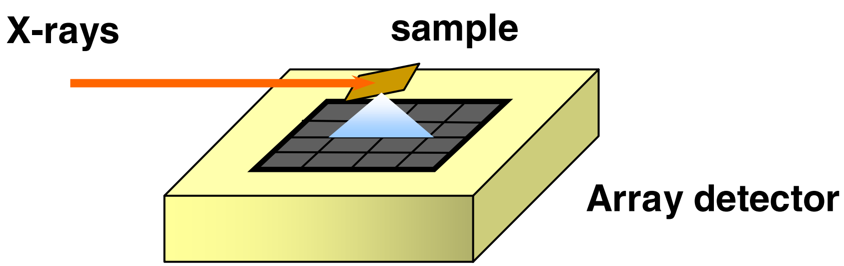
& Array detector

3mm in dia. 4ch,
150 μm, ε =80%

0.5 × 2mm × (4 × 2)ch,
0.5 × 1mm × (4 × 2)ch,
50 μm (monolithic)



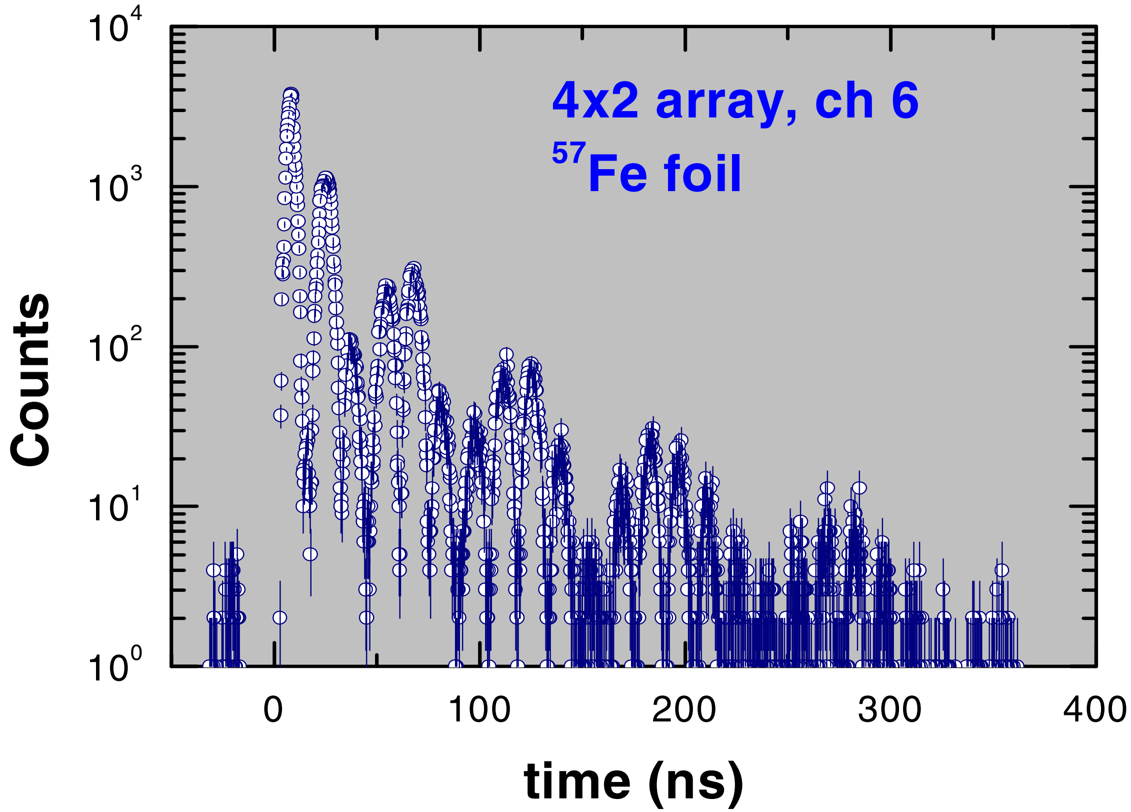
Phonon energy spectroscopy using a neV resolution



3 × 5mm × (8 × 2)ch, 150 μm

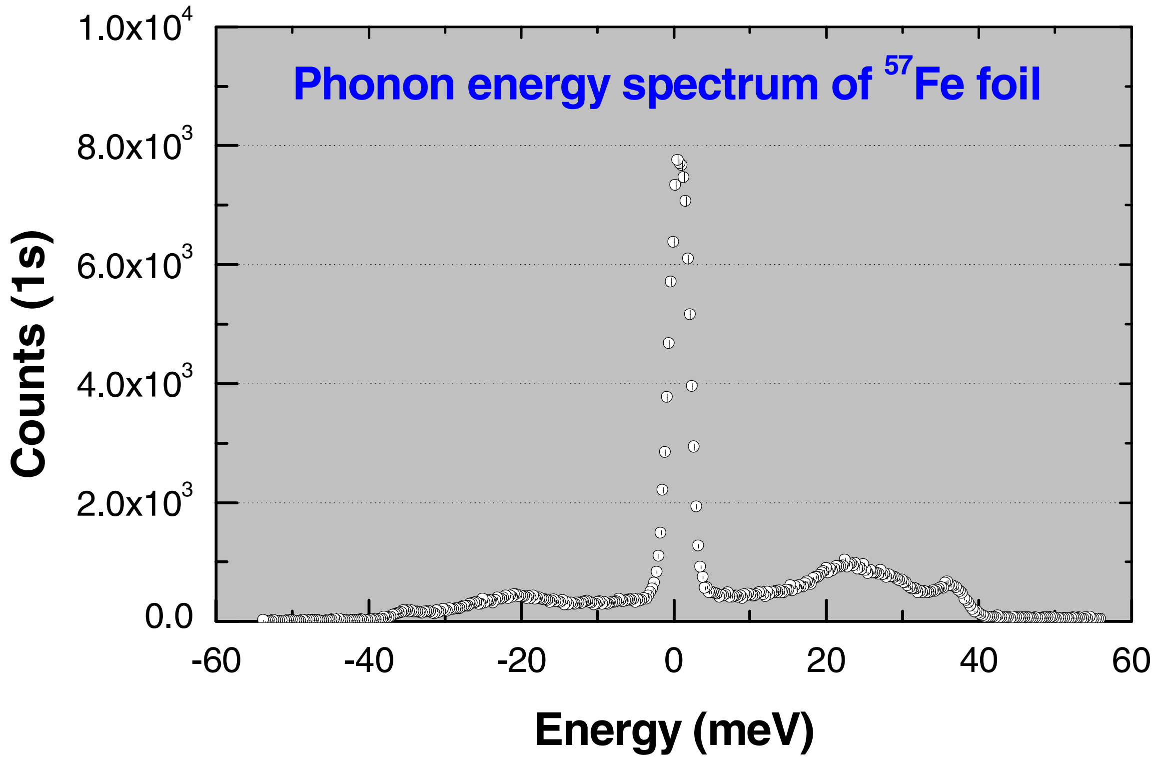
Mössbauer time spectrum measured with the APD detector

Quantum beat, exhibiting the interference of hyperfine transitions, is seen.



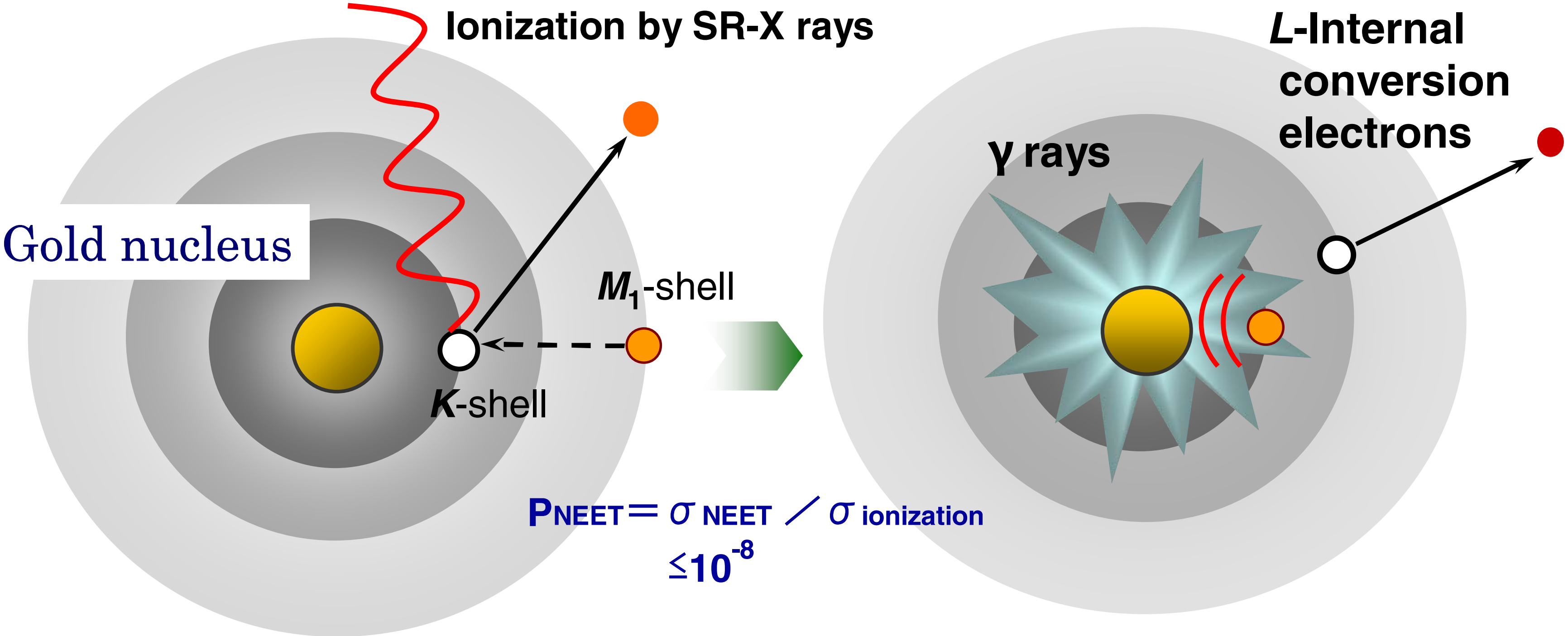
By Time-to-Amplitude Converter (ORTEC567)

Nuclear inelastic scattering



Nuclear Excitation by Electron Transition (NEET)

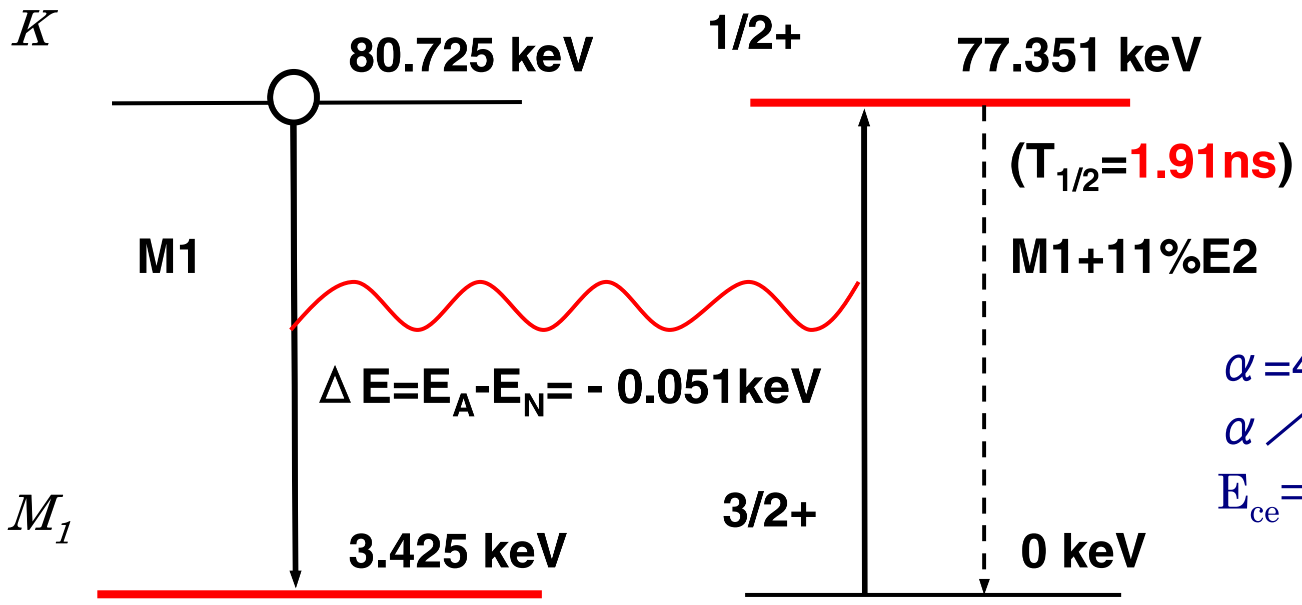
Ex. ^{197}Au



***K*-holes are made by ionization, and filled by an atomic transition from an outer orbit.**

The nucleus is excited, followed by emitting radiation with a lifetime of the excited level.

NEET on ^{197}Au



α =4.36

α ／（α ＋1）＝0.81

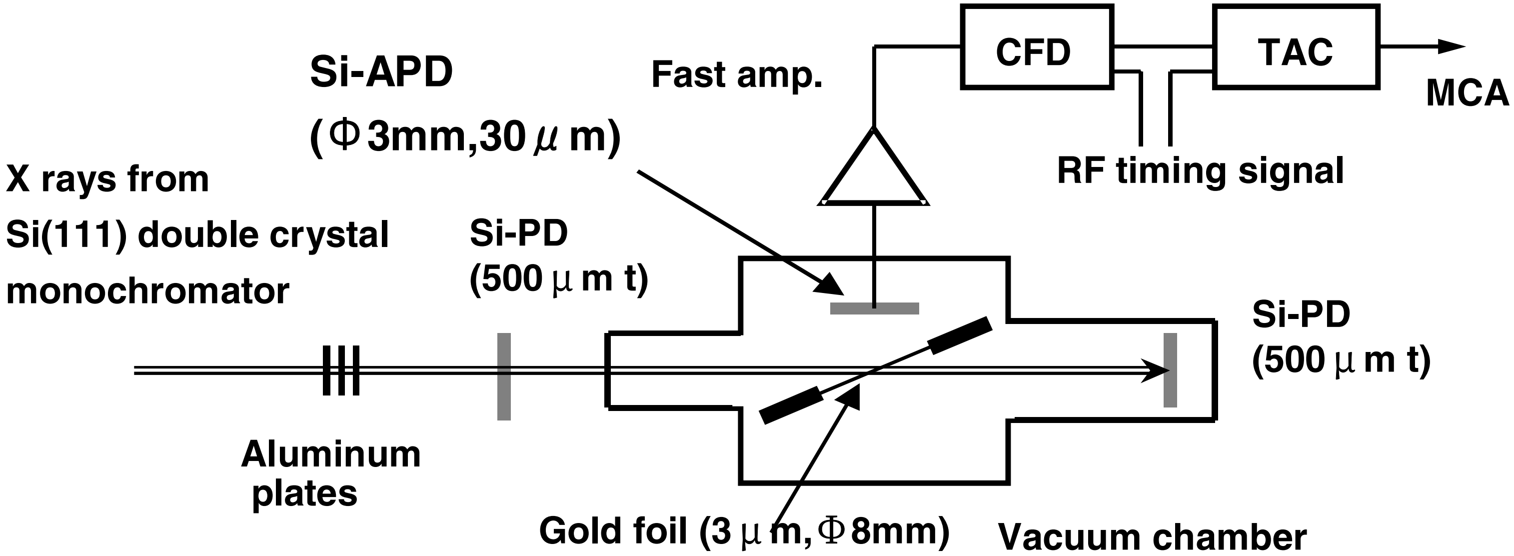
$E_{ce}=E_{\gamma}-E_{b}$

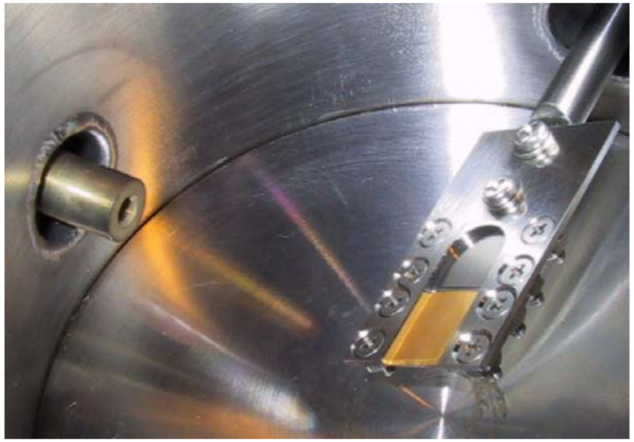
Gold atom(Z=79)

^{197}Au nucleus

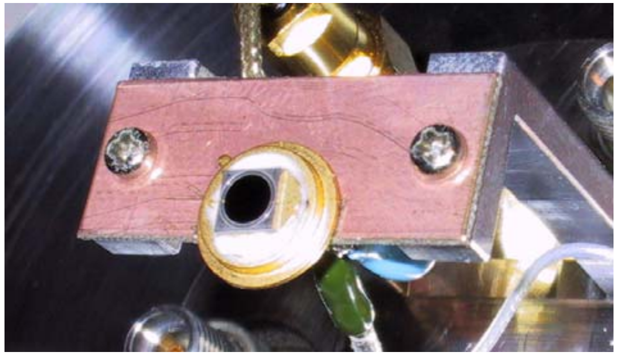
NEET experiment at SPring-8 BL09XU

The detector system has been developed in PF.

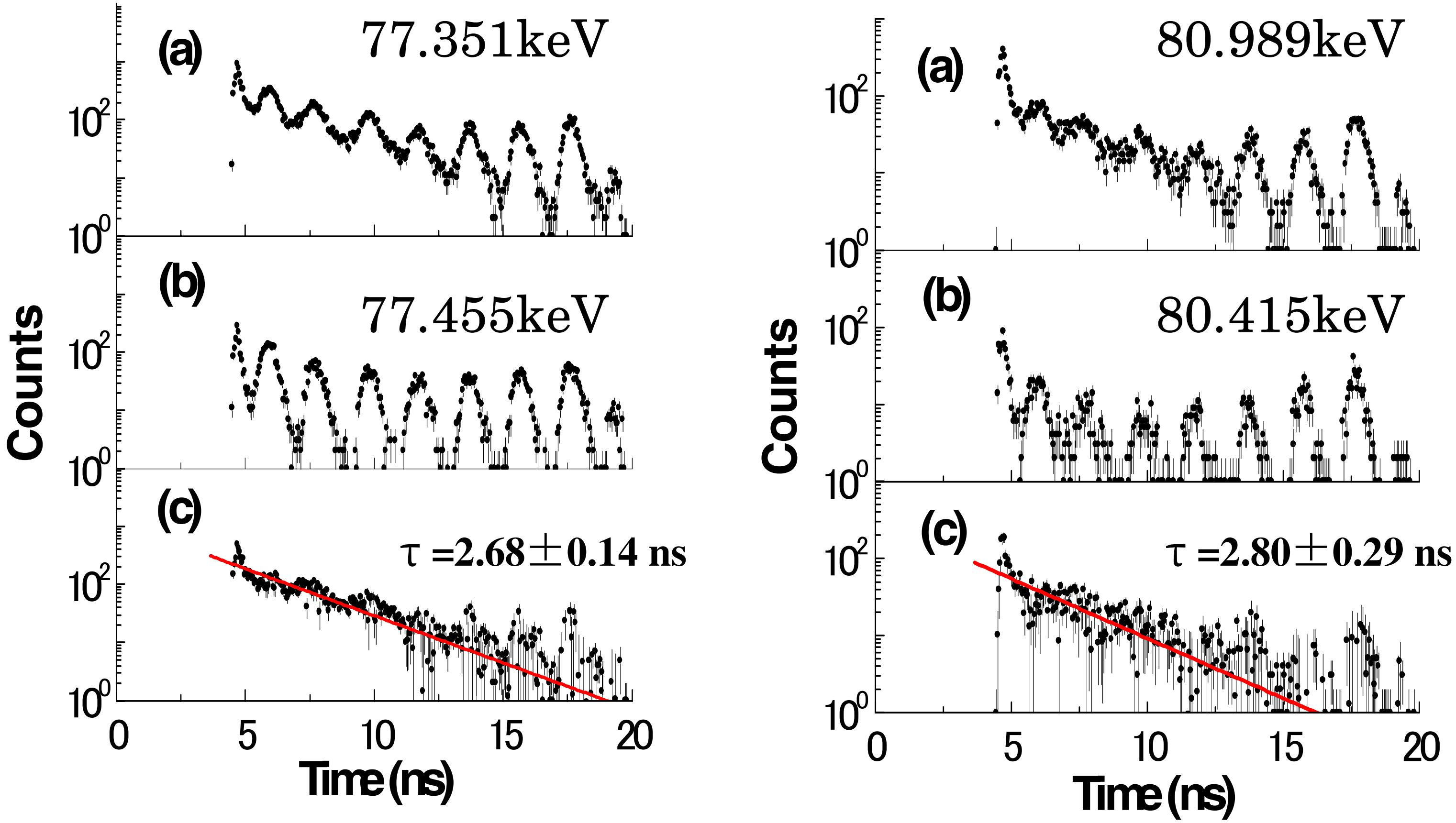




Detecting Internal conversion electrons



Time spectra of Nuclear resonant (left) & NEET（right）



$T_{1/2}$=1.91ns→ τ = 2.76ns

The NEET probability

$P_N = \sigma_N / \sigma_K,$

σ_K : Photoelectric cross section of the K-shell (= $(2.18 \pm 0.06) \times 10^{-21}$ cm^2)

σ_N: the NEET cross section

σ_R : the effective nuclear resonant cross section by an incident beam width of W(eV)

$\sigma_N / \sigma_R = (N_N / I_N) / (N_R / I_R),$

N_N, N_R : numbers of events, observed at the resonance and the NEET

I_N, I_R : incident photon numbers, measured at the resonance and the NEET

N_N = 2994 ± 101 (16091sec), $I_N = (10.54 \pm 0.10) \times 10^{13}$

N_R = 9878 ± 169 (7466sec), $I_R = (5.04 \pm 0.06) \times 10^{13}$

$\sigma_R = (\Gamma / W)\, f_p\, \sigma_0,$

Γ : Width of resonance line (=$(2.38 \pm 0.02) \times 10^{-7}$ eV, FWHM),

W : Width of incident x-rays(=(19 ± 2) eV, FWHM),

f_p :Factor depending on the spectral function(= π / 2),

nuclear resonance : Lorentzian, incident x-rays : approximated by triangle

σ_0 :Maximum resonance cross section (=$(3.86 \pm 0.05) \times 10^{-20}$ cm^2).

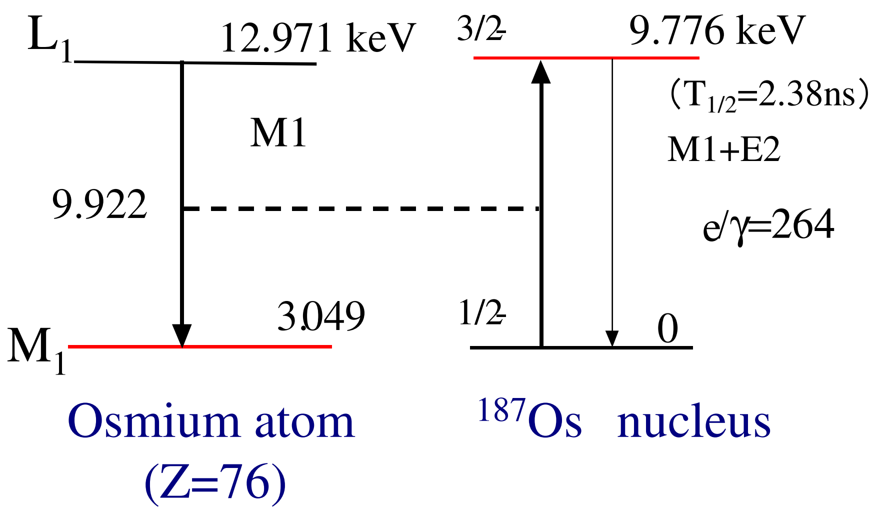
$\sigma_R = 7.59 \times 10^{-28}$ cm^2, $\sigma_N / \sigma_R = 1.45 \times 10^{-1}$,

$P_N = \sigma_N / \sigma_K = 1.10 \times 10^{-28} / 2.18 \times 10^{-21}.$

$P_N = (5.0 \pm 0.6) \times 10^{-8}$ (Phys.Rev.Lett. 85,1831(2000))

	E_{ion} (keV)	E_M(keV)	E_N (keV)	$T_{1/2}$(ns)	Δ E(keV)	P_{NEET} (cal)
^{193}Ir(Z=77) 62.7%	76.111 (*K*)	3.174(M_1)	73.044	6.09	-0.107	2.0×10^{-9}
^{189}Os(Z=76) 16.1%	73.856 (*K*)	3.049(M_1)	69.537	1.62	1.270	1.1×10^{-10}
^{187}Os(Z=76) 1.6%	12.971(L_1)	3.049(M_1)	*9.776 (9.746)	2.38	0.146	$1\text{x}10^{-8}$?

Being prepared at PF-AR NW2



Conclusions

Nuclear excitation experiments by using SR-X rays

Present
Width of X-ray pulses: 50-200ps (FWHM)
Half-life of excited levels($T_{1/2}$): order of nanosecond
Res.- ^{40}K: 4ns （29.8keV）
NEET- ^{187}Os: 2.4ns （9.8keV）

→

Width of X-ray pulses： 100fs-1ps
$T_{1/2}$ ： extended to picosecond region
ex. Res.- ^{155}Gd: 193ps （60.0keV）

PF-AR: Bunch Purity should be improved & be kept in less than 10^{-8}, even at the second bucket!